THE GEOLOGY AND PETROGRAPHY OF THE CLARENCETOWN-PATERSON DISTRICT.

Part iii. A Study of the Main Glacial Beds at Seaham.

By G. D. Osborne, B.Sc., Dept. of Geology, University of Sydney.

(Plate xiii; 1 Text-figure.)

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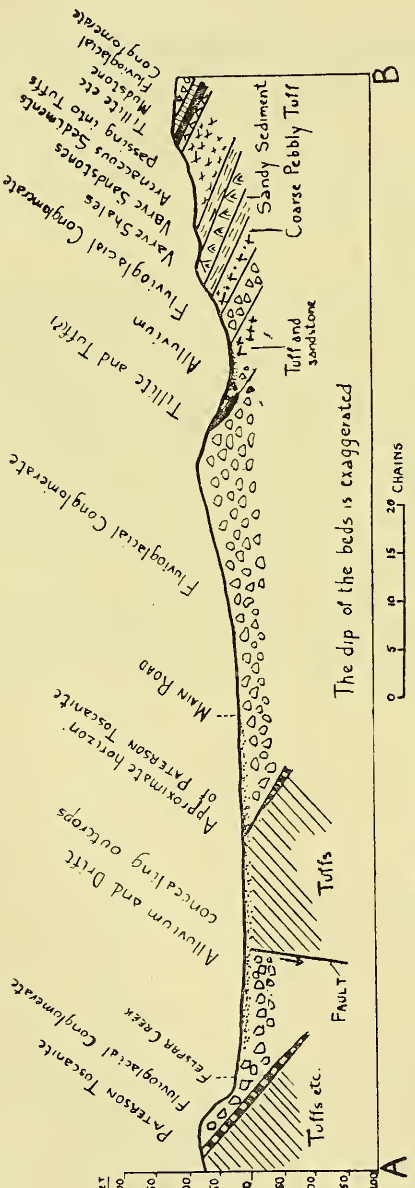
Introductory.

In the account of the stratigraphy of the Kuttung Series in the Clarencetown-Paterson district (Osborne, 1922) it was pointed out that, although difficult to classify satisfactorily, the Kuttung Series, in this, the type, area, showed a more or less well-marked threefold division into the Basal, Volcanic and Glacial Stages. The last of these was subdivided into a Lower Portion and the Main Glacial Beds, these two being separated by the dellenite-toscanite lava (Paterson type), which was found to occupy a constant stratigraphical horizon throughout the area. In the Lower Portion there occurs a definite band of varve rock, as well as a great thickness of arenaceous sediments, but in the Main Glacial Beds we have an assemblage of rocks which show unmistakable evidence of the existence of a pronounced glaciation during the period of their accumulation.

The best locality in the Lower Hunter Valley to study the Main Glacial Beds is at the village of Seaham and in its immediate neighbourhood. This was recognised by C. A. Sussmilch who described some features of them in 1919 (Sussmilch and David, 1919), giving the following section:—

	Feet.
Grey tuffaceous mudstones	264
Tillite Bed (No. 5 Bed)	75
Varve Shales	100
Tillite Bed (No. 4 Bed)	80
White Tuffs	55
Tillite Bed (No. 3 Bed)	200
White Tuffs	315
Varve Shales (with contortions)	110
Fluvio-glacial conglomerate (No. 2 Bed)	50
Tuffs (with conglomerates)	220
Fluvio-glacial conglomerate (No. 1 Bed)	270
Total	1,739

The above section, however, gives only the broad features of the succession. In addition to the statement of the sequence, Sussmilch described certain of the units in some detail. Subsequent to this account, the present writer wrote something upon the distribution of the various units in the Glacial Stage (*loc. cit.* pp. 193-4), but nothing of a detailed nature was published. Later, in 1922, when visiting Seaham, it was noticed that excavations in connection with the construction of the Pipe Line from the Chichester Dam to Newcastle had exposed a very interesting section of the rocks, and it was decided to measure the section while the cuttings were fresh, and complete the detailed study of the beds. The present paper is the outcome of this work, together with certain observations made during the main survey in 1921.



Text-fig. 1.—Section along Pipe Line, A—B on map (Plate xiii).

SEQUENCE OF THE MAIN GLACIAL BEDS.

Every horizon of any importance was traversed in the field and the Map (Plate xiii) is the outcome of this survey. Along the Pipe Line, A—B, the section indicated in Text-fig. 1 is to be found. (Unfortunately as a result of weathering, soil creep, etc., the section at the present time is much obscured in contrast with its original appearance.)

Beginning at the main road just beyond (to the north of) its crossing of Felspar Creek, the Paterson toscanite dips to the south. This is overlain by a notable fluvio-glacial conglomerate, the salient features of which have been given by Mr. Sussmilch. In this unit there is a band of gravel differing markedly from the rest of the deposit, in that there is a greater continuity of bedding, and an approach to uniformity in the size of the pebbles. It also possesses a characteristic property connected with the cementing material, the pebbles being coated with a film, purplish in colour, and probably composed of some compound containing manganese.

These features made this horizon of distinct stratigraphical value in helping to determine the position of a fault in the area.

The fluvio-glacial conglomerates occur sporadically through the alluvium of Felspar Creek, but are stopped by a fault which seems to throw them against the tuffaceous sandstones under the Paterson toscanite. These sandstones can be found forming the base of the hills immediately to the south of Felspar Creek, on the west side of the main road. The

Paterson flow, overlying the tuffaceous sandstones, is difficult to find on account of the heavy mantle of talus material and also because of its small thickness hereabouts. It does not outcrop in the Pipe Line cutting, which here is shallow, but, as will be seen on the map, it occurs both to the west and east of the section. Continuing along the section the conglomerate, with its distinctive pebble band, follows the toscanite. A little to the west of the Pipe Line the outcrop of these fluvio-glacial conglomerates comprises a number of large boulders derived from the underlying igneous rock, which on disintegrating, are apt to be mistaken for outcrops of the lava *in situ*. On these hills to the west of the main road there is an abundance of pebbles showing faint glacial striae.

Following the conglomerate comes an extremely hard rock consisting of angular fragments set in a matrix. This combines some of the features of a tuff with those of a tillite, and there is no doubt in the writer's mind that it is glacial in origin, at least in part. Continuing south, a small creek is crossed, and there then follows a coarse tuff which varies in texture from place to place. The dip on these beds is S 20° W at 8°. Overlying the tuffs comes the second definite bed of fluvio-glacial conglomerate. This unit contains many faintly scratched pebbles and outcrops well to the east. Following it are some interesting rocks which seem to be coarse glacial sediments mixed with tuff. The lower portion of these beds is composed of pebbly material, and this passes into finer sediment and then into a zone of transition to the overlying varve-rock. This zone of transition possesses some beautiful contortions in which the fine material is intimately mixed with the arenaceous sediment.

The varve-rocks now succeeding constitute the main horizon of these in the district. They show evidence of contemporaneous contortion and of local minor dislocations. They are overlain by sandy sediments showing, in places, evidences of seasonal deposition and may be called "varve sandstones". The textures in these rocks comprise three distinct degrees, the grainsize increasing towards the top, where the rocks are undoubtedly mixed with some tuff.

Summarising the section thus far we have (*see* Text-fig. 1):

	Thickness in Feet.
Fluvio-glacial Conglomerate (Felspar Creek horizon)	420
Felspar Creek Tillite	10
Acid Tuff (?)	50
Fluvio-glacial Conglomerate with local tillitic masses	40
Coarse Tuff with pebbles	50
White sandy sediment with transition to overlying varve rock	100
Main Fine-grained Varve Rock	100
Fine Sandy Sediment (Varve Sandstone)	80
Fine-grained Sediments	100
Coarse Tuff	70
Total	1,020

Overlying the coarse tuff comes a series of layers composed of both tillitic material and glacial mudstones, some showing varve structures and indications of having been strongly contorted before consolidation. These layers are present in the following order, ascending stratigraphically:

	Feet.
Limonitic contorted varve rock	2
Hard calcareous tillite	1½
Tillite and purple varve rock	3
Grey mudstones	5
Total	11½

The above rocks include the most definite tillite occurring in the whole district.

The sequence after this point is not clearly defined, chiefly owing to the intermittent nature of the outcrops and the lack of persistence of the units. But the general features are as follows: The tillite material is followed by glacial mudstone in which one notable erratic of granite occurs. This underlies a definite fluvio-glacial conglomerate which has been referred to by Mr. Sussmilch as No. 3 Bed. Overlying this, just to the south of the Maitland road, are a number of units comprising tillite, agglomerate and mudstone, while in a similar position to the east is the second unit of fine varve rock.

Tuffs now succeed the rocks just mentioned and also a fifth band of tillite, this being followed by a slate-blue rock, fine-grained and calcareous, which is extremely tough and resistant to weathering. In the centre of this unit there is a less competent portion, not unlike the varve rocks in many respects. Succeeding this horizon comes a drab-coloured mudstone, sometimes banded and locally conglomeratic, which ends under a distinctive conglomerate with tuff bands, which has been regarded by Sussmilch as being the basal unit in the Permian or Permo-Carboniferous System for this district. Certainly this unit seems to differ in general facies from the conglomerates of the Kuttung Series, and it is clear that its horizon is very close to the junction line of the two systems, for, at a very short distance to the south (i.e. in the direction of dip), there occurs decomposed basalt which the writer thinks belongs to the Lower Marine Stage of the Permian System. It would appear that this conglomerate, if Permo-Carboniferous in age, has overlapped some of the older members of the Lower Marine Series, such as the Lochinvar shales, etc.

Thus a generalised section of the rocks following the end point of the Pipe Line section is as follows:

	Feet.
Mudstones with erratics	100
Fluvio-glacial conglomerate	200
Tuffs and agglomerate	50
Tillite	60
Varve rock (second horizon)	100
Tuffs	80
Tillitic rock	50
Fine-grained calcareous rock	50
Drab-coloured mudstone	180
Total	870

The total thickness, therefore, of the glacial beds indicated in the sections described above is 1,890 feet.

Concise Account of the Distribution of the Main Glacial Beds.

The most complete sections have been measured along the Pipe Line and to the south of the turn in the Maitland road near the cemetery, but a consideration of the distribution of the various beds gives some interesting information. The present description can only be brief.

The basal member of the series, the Felspar Creek conglomerate, is well developed on the left bank of Felspar Creek near its confluence with the Williams River and again, as a result of the fault, on the hills to the west of the main road a little to the north of the hotel. Also, in the paddocks of the Porphyry Estate, the boulders from the tillitic mass are very conspicuous. To the west-north-west of the hotel, in the upper portion of a small creek, there is a large mass of tuff developed on the top of the Felspar Creek conglomerate. This tuff is pebbly in places. The angular-fragmental rock occurring on the Pipe Line appears to be restricted, but the succeeding tillitic conglomerate, on which the Post Office stands, is fairly persistent. The main varve-rock horizon extends uninterruptedly from the Raymond Terrace road to the western margin of the region mapped, and the rocks show the usual varve structures and contortion zones until one comes to a spot, marked with a cross on the map, where a zone of brecciation or disturbance is found at the top of the rocks; a somewhat similar set of features occurs near the main road a little above the hotel. These structures will be described in detail later.

The interesting arenaceous rocks and coarse tuffs following the varve rock go across the village in good development. The zone of tillite and contorted shale which is found just at the end of the Pipe Line section overlying the coarse tuffs, contains a band of purple material which can be traced as shown on the map. South from the main road there is a lack of persistence of units and irregular masses of tillite, tuff, conglomerate, and mudstone are associated in haphazard fashion. Some of these tillitic units seem to be in much the same position as they were originally, when dumped by glaciers, not having suffered subsequent sorting by water action as did much of the sediment in the district.

The restricted outcrop of the second horizon of varve rock, on the Raymond Terrace road and in the cemetery, suggests that they were developed in isolated basins, between which were dumped masses of till, etc. One or two of the horizons succeeding the second unit of varve rock are well developed and show out quite well physiographically.

Structure of the Area.

The structure of the area under consideration is quite simple. The rocks show a general dip towards the south, the values of reliable dips showing that there is slight rolling in the strata. Near Felspar Creek the dip has been measured, approximately only, at 15° in a southerly direction, while the lower varve rock gives reliable dips of S. 12° W. at 30°, and S. 14° W. at 12° at the main quarry and near the Pipe Line respectively. It might be mentioned here that dips upon varve rock can only be regarded as reliable when measured upon exposures such as are afforded by fairly large quarries or recently eroded creek banks where creep and minor dislocations can be proved absent.

The east and west alignment of the rocks forms the nose or front of the flatly-arched plunging anticline which, in a former paper, was described as the Williams River anticline. In addition to minor dislocations there is one important fault. It is a strike fault, and its probable position is shown on the map. The duplication of some of the beds, bringing about the adjacency of rocks which are separated by an appreciable stratigraphical interval and, to a small extent, the physiographic features comprise the evidence for the existence of the fault. Thus the Paterson toscanite has been found on both sides of Felspar Creek which flows parallel to its strike. In fact, the repetition of the lava to the south of the creek, in the first place, formed the key to the structural features, and it was because of the difficulty of locating the southern outcrop of the toscanite (as has been indicated above) that the fault was not apparent during the former, less detailed, survey of the Seaham district.

The fault is normal, and has an estimated throw of 450 feet, assuming, as is probable, that it dips steeply. It is interesting to note that there is no clear sign of the fault crossing the Williams River, since the toscanite and associated lavas do not appear to be duplicated to the east of Porphyry Point. However, the locality where one would expect to find the faulted outcrop of the Paterson lavas is given over to swamps and heavy alluvium, which would obscure the structural features. If the fault does not cross the river it is possible either that it dies out towards the east or, turning in its trend, joins up with the large fault which runs along the Williams River north from Raymond Terrace towards the east of Mt. Gilmore.

Lithology and Petrography.

A considerable amount of time has been spent in the petrological examination of these glacial beds. The majority of the horizons have been studied with the microscope, but in some cases the megascopic features only have been noted. In the following discussion the rocks will be taken in ascending stratigraphical order as far as is practicable. It should be pointed out that the truly igneous rocks, e.g., the tuffs and patches of agglomerate, will not be considered in much detail, as they will be included in the chapter on the petrography of the Kuttung Series which is now in preparation. The numbers cited refer to the specimens in the writer's collection.

The lithology of the Felspar Creek conglomerates is interesting. The boulders consist of a large variety of acidic types of igneous rocks with subordinate numbers of fine metamorphic and sedimentary rocks, quartzites being predominant among these. C. A. Sussmilch has described certain features of this horizon: while much of it is fluvio-glacial, there are portions which consist of almost true tillite. *Specimen 463* of this rock, collected from the Pipe Line, shows, under the microscope, the presence of volcanic fragments, altered orthoclase and a little plagioclase set in fine matrix. Among the volcanic fragments there are some almost holohyaline rocks, in which banding and flow structure are conspicuous. Along some of the bands, haematite has separated by a process of devitrification. Microlitic felspar and some secondary silica are also present.

Quite a number of volcanic inclusions have features which suggest cognate origin. They do not remind one of the underlying lavas in the Kuttung Series. In one or two fragments complete devitrification has occurred, while carbonation has developed throughout many of the rocks.

The felspar fragments are not very abundant, the orthoclase being either kaolinised or replaced by calcite. Plagioclase is rare and its composition is a matter of doubt. The quartz is extremely angular in most cases, but some of it shows evidence of having been corroded. There seems to be an absence of pieces of quartz showing pseudo-inclusions of groundmass, such as is characteristic of the quartz in the acid lavas of the Volcanic Stage.

The matrix is composed of numerous patches of a dull brown material, whitish by reflected light, but under high magnification seen to be composed of calcite or, at all events, of secondary carbonates. These patches, which are very feathery in outline, probably are the result of infiltration. Associated with the carbonate material there is chlorite, and it is possible that this has developed from felspar which has been replaced.

The rest of the matrix is composed of innumerable specks of chlorite and other indeterminate material, together with a notable amount of pyrites, present in sections nearly rectangular in outline. Patches of recrystallised quartz occur in places.

Specimen 464. Locality, Pipe Line, west of the hotel.

Megascopically seen to be composed of angular and subangular fragments of felsite, porphyry and chert cemented by a hard fawn-coloured material through which are scattered numerous quartz crystals.

Microscopical characters: As in *463*, there is a prevalence of vitrophyric rock types, many of which are in process of devitrification or otherwise altered. Thus haematite may be developing along lines in a fluidal rock, or silicification or carbonation is in evidence. Some of the fragments are pieces of large banded spherulites which are kaolinised.

One specimen recalls a recrystallised shale or siliceous sediment. Secondary quartz and tiny wisps of muscovite were seen. The muscovite had evidently been developed from the cement which had formerly held the quartz grains together. Felspar chips are present, many being of fairly acid plagioclase. There is notable absence of albitised rock fragments. Similar patches of secondary carbonate, as seen in *463*, are to be seen associated with silica in the matrix. The rock is a contaminated tillite, some tuffaceous material being present.

Specimen 468. Locality, east-west road running from the main road towards the varve rock quarry.

This rock is like a sandstone at first sight, but under the microscope shows many features which are directly connected with its glacial origin. In the first place the quartz grains, which constitute the greater part of the fragments, are angular or subangular, and there is evidence of little transport. The size of the grains is fairly regular, being about 0.15 mm. in average diameter.

There is quite a large amount of felspar, both orthoclase and plagioclase. The orthoclase is not strongly kaolinised, and much of the plagioclase is albite, which does not look spongy like the secondary albite often seen in albitised rocks. There is also a little altered biotite, and many grains of dull brownish material which shows up like haematite at times, and kaolin at others.

Under the high magnification the matrix presents some interesting features. There is an extremely fine-grained mass of material which is certainly partly silica. This is besprinkled with points of calcite, muscovite, some haematite and kaolin. In addition to the silica mentioned above, there is some of secondary nature, which appears just like the quartz of silicified lavas. The silica in the former category does not look quite like quartz which has been introduced and yet hardly looks as if accumulated in its present state.

Many of the plagioclase pieces are perceptibly bent, the significance of this not being known. The rock is a glacial sandstone. This material, when showing evidence of seasonal deposition, has been called "varve sandstone."

Specimen 469. Locality, Pipe Line just above the main varve rock horizon.

Megascopically, the rock looks like a tuffaceous sandstone, possessing a white colour, weathering to fawn.

Microscopical characters: The rock shows the presence of fragments of minerals, and a few pieces of rock. The grainsize of the rock chips varies from 0.6 mm. to 1.5 mm.

The plagioclase is albite and there is more of it than orthoclase, which is somewhat kaolinised. Many of the quartz fragments are very slender in form while the majority are more equidimensional, all showing quite sharp extinction. Calcite, in ragged patches, is present in notable amount, but subsidiary pieces, more regularly bounded, are present, probably representing the replacement of angular chips of felspar. One or two pieces of the calcite show cleavage rather well.

Haematite is also abundant. Among the rock fragments, devitrified and silicified rhyolites (?) occur, some of which have been originally spherulitic. In the matrix there is much secondary silica, often found wrapping around the rock fragments, and possessing features similar to that in specimen *468*. Some chlorite is present, and also tiny pieces of felspar spherulites which have not suffered by decomposition.

Specimen 472. Locality, Pipe Line, just north of the main road, near the cemetery.

This is from the horizon of the tillite originally discovered by Professor David in 1914. The rock is grey and hard, and is composed of angular fragments, and some rounded pebbles, set in a very compact matrix which is fine-grained, and possesses many quartz grains. The rock weathers to either a yellow or purple colour, being of the latter colour at the place of original discovery at the turn in the Maitland Road.

Under the microscope, apart from the large fragments which are composed of compacted varve rock or of foreign rock types, igneous and sedimentary, there is a lot of consolidated till, too fine at times to be resolved by the microscope, but, where a little coarser, seen to be composed of angular quartz and felspar, chlorite, and secondary material, together with indeterminate constituents.

Specimen 476. Locality, Raymond Terrace road, just below the second horizon of varve rock.

In hand-specimen it is seen to be essentially a quartzose tuff. The size of the fragments varies from place to place to a small degree, the average grainsize being 2 mm.

Microscopical characters: In thin section the tuffaceous nature of the rock is apparent, although there is also a little glacial sediment. Thus one sees fragments of rocks, many of which are cognate in origin, also angular quartz grains which may have been blown out from a volcanic centre, and other subsidiary constituents. Mingled with all this material are strings of fine glacial sediment.

The rock fragments comprise devitrified rhyolites, also some silicified rocks with phenocrysts of plagioclase and altered orthoclase. In some of the rocks, structures of peculiar pattern have resulted owing to the selective replacement, by haematite, of certain constituents in various rocks. Secondary calcite is not abundant. In the matrix there is much secondary silica, some secondary muscovite, a little chlorite as well as other indeterminate constituents. The muscovite and silica, which are intimately associated, occur in finely divided state and are often found mantling the large rock fragments. All these features suggest the possibility of the mica being autogenic, due to reactions which have gone on in the clayey sediment. Some greenish silicate, probably one of the chlorite group, is present, and also in the matrix some pieces of fairly fresh spherulitic felspar.

Specimen 479.—This is the tuff associated with the tillite on the Raymond Terrace road just south of the park and overlying the second unit of varve rock. In hand-specimen it suggests a glacial origin, being similar to the highest tillite on the Pipe Line section.

Microscopical characters: Under the microscope it possesses features which stamp it definitely as glacial. Some of the material is similar to the coarser layers of the varve rock. Quartz chips, fresh acid plagioclase, and fragments of volcanic rocks are set in an exceedingly fine matrix. There are abrupt variations in the size of the fragments of rock. Some of these are haematitised.

Most of the rock types are acidic, volcanic in nature. The extremely angular nature of the quartz chips is noticeable. Orthoclase is being replaced by both albite and calcite and some pretty patterns have resulted by this dual replacement of the one grain. Elsewhere the orthoclase shows slight kaolinisation. The plagioclase is fresh albite and oligoclase. The matrix is exceedingly fine and much of it cannot be resolved by the microscope. It appears to contain a fair amount of finely divided silica.

Specimen 480. Locality, Raymond Terrace road, just at its junction with Whyten Street.

An extremely finely-textured rock which effervesces readily with acid. It possesses little variation in grainsize and is very massive. It is a sedimentary rock and shows swirl and current structures.

Microscopically, it is seen to consist of numerous chips of quartz which vary little in grainsize, and fairly fresh acid plagioclase, together with some very ragged iron-ore set in an exceedingly fine groundmass. In this matrix there occurs some silica and possibly some chlorite, but the most important constituent is calcite, and in some cases this may be replacing tiny mineral chips. The derivation of this rock is a matter of doubt, but the general facies strongly suggests a fine glacial sediment.

Specimen 492.—This is from the zone of complication between the main varve rock and the underlying tuffs just west of the road near the hotel. The rock is very pretty and shows strings of tuff, with a fairly uniform texture, seaming through the varve rock.

Microscopical characters: Under the microscope the varve-shale material is seen to be very fine, sometimes possessing banding. In it are some detached rock fragments which are distinct in nature from the pieces in the tuffs. The material of the tuff stringers is much altered by deposition of haematite, while quartz crystals are quite abundant.

A number of slides of the varve rocks have been examined. The lamination is, of course, very evident under the microscope, but often, in addition to the layers visible megascopically, there are some small bands, which can only be picked up in thin section. The coarser layers are bounded by sharp lines downward, but grade up into the following fine or winter layers. The coarser layers contain angular quartz and felspar and tiny rock fragments and much irresolvable material, while the constituents of the fine layers are almost beyond identification. Haematite is abundant in some of the coarser layers.

Interesting Structures in Certain Rocks.

Peculiar relationships between some of the varve rocks and either sandy or tuffaceous rock are to be found in many parts of the area. Near the hotel, for example, just to the west of the road, and also at a number of places further to the west, one finds specimens showing intimate co-mingling of the two units, shale and tuff or sandy sediment. At times there is a suggestion that the tuffaceous material has been injected into the varve rock, while at other times the reverse action seems to be indicated. On account of the degree to which these features are sometimes developed, one is apt to mistake some of the rocks for agglomerates. It seems best to explain some of the associations as having been brought about during the accumulation of the glacial mud and tuffaceous material.

Other structures similar to those that may be explained as just indicated, seem, as they are studied carefully, to have been produced as a result of the dragging force of moving ice. At the place marked with a cross on the map, west of the Pipe Line, one finds brecciation in the zone of transition from the underlying varve rock to the tuffs. Layers of twisted varve rock pass into breccia bands, followed by more shale and finally massive tuff. In the breccia bands some extremely complicated relationships exist. Generally the varve material is found threading its way through the fairly sharply broken tuff, but at times a confused mass is found.

It would appear that the tuffs developed upon the fine sediments, alternations occurring at the close of the shale accumulation period. The interference by the ice movement shattered some of the tuff, which had evidently become more coherent than the underlying varve rock which, though supporting the overlying tuffs (of no great thickness) was still plastic enough to be squeezed into the fractured tuff. Thus the varve rock gives the appearance of having intruded the tuff.

Chemical Considerations.

The author carried out an analysis of a fresh portion of varve rock in order to see what bearing the results would have upon the question of the origin of the sediment. The sample was taken from a thick winter layer of compacted rock-flour, occurring in the more easterly of the two quarries at Seaham. The results are given in the table below. Along with the analysis are placed four other analyses of glacial sediments.

	1	2	3	4	5
SiO_2	78.41	53.40	56.38	61.38	52.00
Al_2O_3	9.32	15.70	17.81	15.58	16.11
Fe_2O_3	.59	—	2.56	3.52	4.69 (Fe₂O₃ + FeO)
FeO	.25	3.22	5.04	2.58	
MgO	1.72	2.62	2.80	3.12	4.10
CaO	.01	5.65	3.26	2.52	8.26
Na_2O	2.13	1.95	2.13	2.82	2.76
K_2O	4.56	3.14	1.92	2.79	1.74
H_2O+	1.74	3.14	4.30 (H_2O+ and H_2O-)	3.99 (H_2O+ and H_2O-)	9.64 (H_2O+ and H_2O-)
H_2O-	.85	.18			
TiO_2	less than .01	.93	.40	.48	—
P_2O_5	.10	.27	.21	.14	
MnO	.01	.05	—	—	—
CO_2	absent	6.24	3.40	.78	—
FeS_2	—	3.64	—	—	—
SO_2	—	—	—	—	.09
SrO	—	.09	—	—	—
	99.70	100.22	100.21	99.70	99.39

Specific gravity of No. 1=2.494 at 21° C.

1. Varve Rock, Seaham, N.S.W. Anal. G. D. Osborne.
2. Laminated Slate, near Adelaide, S.A. (Mawson, 1912). Anal. W. S. Chapman.
3. Dwyka Tillite, S. Africa. Quoted by T. L. Walker (1921).
4. Ojibway Clay, North-western Quebec. Anal. T. L. Walker.
5. Stratified Glacial Clay. Quoted by M. E. Wilson (1913).

Examining the figures for the Seaham rock one is struck with the high percentage of silica. This, no doubt, is due to the fact that the glaciers worked over areas of acidic rocks, confirmation of this view being forthcoming in the results of the microscopical examination of the boulder beds associated with the varve rock. Alumina and magnesia are low, and lime is conspicuously so. But the most interesting feature of the analysis is in the values for the alkalies. These total 6.69% in a rock with nearly 80% silica. This without doubt indicates that much of the material that formed the rock, which under conditions of normal weathering would have been leached away, has been retained as a result of the protective action of the glaciers which transported the rock-flour, which later was deposited in a lake. After allotting the requisite amount of alumina to soda and potash to form felspar molecules there is very little left. This latter would be present as kaolin, but its scarcity emphasises the undecomposed nature of the material. Consequent upon the almost complete absence of lime, one must postulate all the soda as being present in the form of albite. The microscopical evidence of the glacial beds as a whole shows the prevalence of albite among the plagioclase felspar, and thus lends support to this view.

The petrographical and chemical study of glacial sediments has not been pursued to any great extent in Australia, although the lithology of many occurrences has been written up, and one or two analyses have been made. But elsewhere a fair amount of attention has from time to time been given to this subject. It will be interesting to notice certain features in connection with the analyses quoted above. Thus it may be pointed out that in all cases there is not a great excess of the molecular proportions of alumina over those of lime, soda and potash combined (some of the lime having been allotted to CO_2). Of course one must not expect to find an absence of kaolin in all glacial clays, since the glaciers which produced the clays may have worked over areas given over to aluminous rocks, such as shales.

T. L. Walker, of Toronto University, has written upon the chemical study of conglomerates (Walker, 1921), and has examined a number of analyses of undoubted glacial rocks and also of some sediments for which a glacial origin might be suspected. He has generalised that the value of the Na_2O/K_2O ratio can be used to test the origin of a sediment, a high value indicating a probable derivation of the material by glacial action, and a low value pointing to the material having been well leached, and thus probably the result of decomposition under conditions other than glacial. He also says: "In case that material were assembled from a wide area of igneous rocks the glacial rock flour should have a composition similar to that given by Clarke as the average composition of igneous rocks. Where gathered from a field where both igneous and sedimentary types are associated the cement should lie between the average igneous and the average sedimentary rock in composition."

The present writer considers that the last paragraph could not be made of general application in connection with glacial areas, because it is highly improbable that any glacial clays possess disintegrated material from such a wide area of rocks, that the analysis of the clays could come under any of the categories mentioned, except, of course, by accident.

Then again, it seems that the validity of relying on the ratio of soda to potash is open to question, since there are many exceptions to the rule that during rock decomposition soda is always leached more readily than potash, and further, there is always the possibility of derivation of rock material from areas where potash is so dominant as to give rise to a value of less than unity for the ratio in question, even though no leaching had occurred.

Structures in Varve Rocks with reference to the Estimation of Geological Time.

Seasonally-banded glacial sediments—varve rock and varve sandstones—have, on numerous occasions, formed the subject of attempts to estimate the time taken for their accumulation. Baron De Geer and his students have done classical work in this direction (De Geer, 1912). R. W. Sayles has contributed a very important memoir upon the subject of seasonal deposition (Sayles, 1919), and has written much that deals with the matter now being considered. As a result of his studies, it is clear that much caution is necessary before one can speak with any degree of certainty upon the duration of the time taken for a glacial deposit to accumulate.

Thus there is evidence, in deposits such as varve rocks, that the complete record is not always preserved, except in those deposits which have originated under deep-water conditions, far removed from disturbing agencies such as contemporaneous erosion or ice movement, the former of which might remove quite a big proportion of material, sweeping it away to be deposited further from the ice front. At Seaham the varve rocks show evidence of contemporaneous erosion in many places. In some cases the erosion has been extensive enough to remove inches of sediment at the place of maximum scour.

Another fact, that must be realised in connection with the estimation of time by the counting of layers, is the possibility of rhythms other than the annual one making their presence felt. It is probable that the effects of daily rhythms may be strong enough to be perceptible, at least under the microscope.

Then again it has been found that material which may appear massive in hand specimen shows, under the microscope, alternations which are due to seasonal deposition. So also, some cases were encountered where material which was massive both megascopically and microscopically, on weathering showed the presence of seasonal bands.

Thus there are at least four factors which may enter into the question and tend to make difficult any attempt to estimate, by counting layers in a large deposit, the time which was taken for its accumulation, and the more one considers these factors and their significance, the more one sees the need for caution in the investigation of this phase of the estimation of geological time. Thus the statement by C. A. Sussmilch that "the 200 feet of these varve shales which occur at Seaham must have taken about 3,000 years to deposit" (because the average width of a pair of seasonal layers is about two-thirds of an inch) is hardly satisfactory in view of the points raised above.

Summary indicating the Significance of some of the foregoing Results.

In the preceding paragraphs a detailed account has been given of the Main Glacial Beds of the Kuttung Series, which outcrop in the Seaham district. A map of the area shows that the beds possess quite simple tectonic features, there being one important strike fault and minor dislocations. Some of the units, in contrast to certain other beds, are discontinuous along their strike; among such units are some tillitic masses which probably represent compacted morainic material which has not been affected by fluvial action. The examination of the sequence in detail shows a total thickness of 1,890 feet of sediment.

The petrographical investigation of the beds gives much interesting information. Apart from the horizon of the Felspar Creek conglomerate, there is a distinct absence of much bouldery or fragmental material derived from the underlying Kuttung lavas. Much of the rock associated with the varve units shows evidence of having been transported by glaciers, in the presence of fresh plagioclase and orthoclase, the latter sometimes being present as spherulites.

A chemical analysis of a portion of varve rock is given, and it is of interest to find nearly 7% of alkalies present, along with high silica and low alumina.

These figures confirm the glacial origin of the rock, by indicating the absence of much kaolinic material, and the presence of silicates which would be decomposed under ordinary conditions of weathering and transport.

Descriptions of brecciated structures and examples of contemporaneous erosion have been given and it is to these features and the associated contemporaneous contortions which the fine varve rock and varve sandstone exhibit, that some attention may be given here.

The significance of all these characteristics is that in the Seaham area there must have been much land ice in late Kuttung times. This land ice at times overrode the sediments and produced the interesting structures already described. In contrast with the sediments developed close to the ice front (like the Seaham rocks), one finds that glacial deposits formed in deep water (often under marine conditions) show an absence of the structures mentioned above. The Tapley's Hill slates or shales occurring near Adelaide, in South Australia, are regarded by Sir Douglas Mawson as being glacial in origin. They are associated with the tillites of the Adelaide Series, and possess laminations due to alternations in the material deposited, and these laminations are somewhat suggestive of varve structures. But contemporaneous contortions, current bedding and erosion features are absent, and the general facies of the rocks strongly suggests accumulation in deep water, with the resulting absence of disturbing agencies. If these Tapley's Hill rocks are aqueo-glacial in origin, their distinction from the Seaham type of deposit is very marked, and, in a general way, one may be justified in concluding, in the absence of any contradictory evidence, that glacial deposits showing contortions, contemporaneous erosion and kindred phenomena, may have been developed close to the ice-front, while evenly-banded rocks, free from contortions, etc. (like the Tapley's Hill shale), indicate deposition at a distance from the ice-front, where disturbances do not occur.

In conclusion, the writer wishes to express his appreciation of the kindness and hospitality extended to him by Mr. L. B. Fisher and family of "Brandon" during his visits to the area in 1922-24; and in connection with the preparation of the paper he is indebted to Professor David and Assistant-Professor Browne for helpful discussion.

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EXPLANATION OF PLATE XIII.

Geological Map of the village of Seaham, showing the outcrops of the Main Glacial Beds of the Kuttung Series.